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Interactive Comment

Interactive comment on "Presentation, calibration and validation of the low-order, DCESS Earth System Model" *by* G. Shaffer et al.

G. Shaffer et al.

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Final Author Response

We acknowledge the considerable time spent and effort made by referee 1 (Guy Munhoven) and anonymous referee 2 in going through our long paper in detail and we appreciate the comments that resulted. It was gratifying that both referees were very positive to the results of our endeavors to develop such a comprehensive but low-order Earth System Model. As specified below, we have gone to considerable lengths to address the points brought up by the referees. As a result, our revised manuscript is a substantial improvement over our original one and more groundwork has been laid for future development of the DCESS model. Below we address the specific comments by the referees in the order received.

Comments on the review by referee 2

Main point

The one major concern of referee 2 was insufficient discussion of the model calibration procedure, especially with regard to the atmosphere and ocean. In our revised version we have doubled the space given to this discussion (new Section 3.2), now describing in detail four calibration steps from atmosphere only through to the complete, coupled model with inputs from the lithosphere and outputs via burial down out of the ocean bioturbated sediment layer. At the same time, we improved the organization of section 3. It is now called - Model solution, calibration and validation - and now includes an initial model solution section based on the first paragraph of the old calibration procedure section. In the new calibration procedure section, readers will now find more complete answers to questions like - How did we arrive at the final, best fit solution? - and - What parameters have been tuned together?

Minor points and technical corrections

The introduction now includes a more complete recent bibliography and a more complete discussion of the features that make the DCESS model unique. In the model description section, a more complete justification is given for neglecting temperature dependence of net primary production of the land biosphere and other model assumptions are more clearly referenced. In the calibration procedure section and associated figure texts, we present more clearly the source of data based profiles and mean ocean values used for comparison with model results in Figures 4 through 7 and in the main text. We did not carry out extra simulations of bomb 14C nor CFCs since the excellent model agreement for the evolution of ocean and atmospheric properties from 1765 to 2000 AD would already appear to attest to the skill of our model with regard to the short term uptake of heat and atmospheric tracers by the ocean (see also below).

In the section on 100,000 year simulations, we now include a comparison with airbourne fraction results from other climate-carbon cycles models. In our discussion and

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conclusions section the phrase - We have put considerable emphasis on and much effort into calibrating the DCESS model to pre-industrial conditions by fitting to available data - now appears to be justified by the detailed description of our actual effort in new Section 3.2 (see above). Also we have expanded the discussion of ocean circulation change in connection to climate change and have included appropriate additional references. The technical issues listed by referee 2 have all been addressed.

Comments on the review by Guy Munhoven

Main points

The three main concerns of G. Munhoven are the choice of our vertical diffusion coefficient profile, the treatment and description of our weathering fluxes and our sediment model choices and description. In the DCESS model, we have implemented a vertical diffusion coefficient profile that is coupled to ocean observations and is motivated by the physics of internal wave breaking. The resulting profile requires only one free parameter, as for the constant vertical diffusion approach used in the HILDA model (Shaffer and Sarmiento, 1995). This profile is similar to profiles used in many Ocean General Circulation Models. An important point here is that the DCESS model is not just a simple extension of the HILDA model but rather includes continuous stratification in the high latitude sector and takes actual ocean topography into consideration. With these improvements, the DCESS model is able to capture steady state, ocean profiles and short term ocean uptakes of heat and carbon dioxide reasonably well with only four free parameters. This helps to justify our approach and also to justify why we can avoid introducing extra free parameters in our ocean physics description a la Siegenthaler and Joos (1992) or Harvey and Huang (2001).

We have revised our section on weathering fluxes (old section 2.6, now new section 2.7) and hope that our improved chain of logic now better guides the readers through this section. However, we retain our treatment of silicate weathering since it is presented in connection with carbonate weathering in a way that underlines the similarities

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and differences between the two. In our improved section, alkalinity sinks and sources are now clearly specified as are the fate of weathering products in terms of river inputs or atmospheric sinks and sources. Units are now clearly stated: silicate, carbonate and old organic carbon weathering as well as lithosphere outgassing all have units of moles of carbon per unit time. Furthermore, we have mentioned the possibility of extending our weathering formulation to include other factors like continental surface area and types of exposed bedrock.

We reorganized and improved our presentation and discussion of the ocean sediment module model along the lines suggested by the referee. Now Appendix A has been divided into 5 subsections, the first of which start with a brief recapitulation of the basic structure and assumption of the module. We eliminated the terms in equations A18 and A20 associated with the effects of organic carbon remineralization since we do not use these terms later on. We have also inserted a new equation (A.23) that represents the reduced sediment model for which new Eq. A.24 (old Eq. A.23) is the solution. Now, as suggested, both equation sets for the two model versions are clearly stated. However, we chose to retain Figure 6 and the discussion of it in section 3.2.2: The new sediment module is such a key part of the DCESS model and long time scale applications of it and we therefore find it important to demonstrate up front that the reduced treatment used in the standard module version performs very well compared to the much slower, more complete, carbonate chemistry treatment. Likewise, it is informative to show the distributions across the bioturbated layer of the different carbon species in the more complete treatment.

In response to another suggestion by the referee, we included in Appendix A the alternative formulation of Zeebe and Zachos (2007) for composition-dependent porosity deeper down within the sediment and we included in section 3.2.1 a test of the different porosity formulations. This test shows that it is important to include depth- and composition-dependent porosity in a sediment module and also that our standard choice works sufficiently well. In a future model version we plan to reconsider this point

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and try to address the problem of how a relatively large component of organic carbon, as we find at shallow depths or at high latitudes, may influence the composition-dependent porosity.

There is no problem with the carbon nor alkalinity conservation in our model in association with organic matter remineralization in the ocean sediment. As now described in more detail in Appendix A, CO2 from organic carbon remineralization in the sediment segment is added as DIC to the appropriate ocean layer and the alkalinity sink associated with this remineralization is subtracted as ALK from that ocean layer. Sources and sinks of DIC and ALK associated with burial are also treated in a correct and consistent manner. There is no model drift for these or any other tracers from the pre-industrial steady state. Our model treats chemical erosion in a consistent manner and, yes, the model can be used to produce synthetic sediment cores since the model retains a record of the properties of sediment buried. This is an application we are addressing in work in progress together with the development of a more complete model for carbon and oxygen isotopes in the sediment.

Minor points and technical corrections

We have replaced q by V as denoting the deep overturning circulation to avoid confusion with the way q was used in the HILDA model papers (Shaffer and Sarmiento, 1995). Likewise we have replaced - lysocline - by - sublysocline transition layer - throughout the paper. The rain ratio is somewhat higher, 0.18, that in recent estimates due to the fact that our new production is somewhat lower than other estimates, but still higher than the HILDA model estimate (Shaffer, 1996), while our calcite production agrees with other estimates. All the technical issues listed by G. Munhoven have been corrected with the following exception: We chose to leave the description of the bioturbation and remineralization rate dependences on organic carbon rain rates and dissolved oxygen concentrations where they are, since this is after the solutions for dissolved oxygen have been presented.

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Model accessibility

One of our basic goals in writing our DCESS model manuscript has been to present all the model details such that interested readers could use the manuscript as a basis for setting up the model in the programming framework of their choice. This goal is now even better satisfied in the revised manuscript as several missing pieces have been supplied and several points have been clarified. We developed and programmed the model in Matlab over the past five years but, due to lack of time and manpower, have yet to produce a fully documented version suitable for general distribution. We will be working on this and expect to have produced such a version within the next year to be placed on the home page of the Danish Center for Earth System Science (www.dcess.dk) and on the GMD home page.

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